Lafayette Instrument
POLYGRAPH

LX4000 and LX5000 EDA Circuit Design and Evolution

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Lafayette Instrument Company provides the most accurate field polygraph technology available today, with products that are robust and durable. For this reason, Lafayette Instrument Company is often regarded as the industry leader in polygraph technology.

The LX4000 and LX5000 data acquisition systems have been successful products that have serviced the polygraph profession in both optimal and sub-optimal, and sometimes harsh, environments. The LX4000 and LX5000 are completely safe for both examiner and examinee, and have a proven track-record of being highly functional in field settings worldwide.

The purpose of this document is to provide information regarding the EDA circuitry used in the LX4000 and the LX5000.

THE LX4000 EDA CIRCUIT

The LX4000 was introduced to the market in 2002. The original LX4000 data acquisition system (DAS) included both a skin-conductance and skin-resistance circuit on the main board. The skin-conductance circuit was never used. The original skin-resistance circuit featured a subject current of 3.6 microamps (0. 0000036 amperes) and the ability to acquire data across a resistance range of 10 kilohms (kΩ) to 1 megohm (MΩ). Even though the normal range of EDA is limited to the range from 50 kΩ to 500 kΩ in laboratory settings, customer feedback indicated a desire for greater EDA range. A new LX4000 circuit was developed during 2004, increasing the range, and increasing the amount of current used to take the measurement. The measurement range was increased from 1 MΩ to 2 MΩ to more completely accommodate the range of EDA values that can be observed in polygraph field settings. Current was increased from 3.6 µA to 10 µA at that time.

Changing the EDA circuit involved adding new electronic components, resulting in an auxiliary circuit board that was installed as a daughter card inside the LX4000 DAS enclosure. The new circuit was provided to existing customers

upon request. To install the new circuit, the DAS unit had to be returned for factory servicing. The EDA daughter card was also added to some DAS devices during new production. Use of the daughter card installation allowed Lafayette to quickly meet demands for new production and servicing of existing units. The latest date of production for devices with the EDA daughter card was 2006. LX4000 DAS units sold after 2006 had the new EDA circuit included on the main board.

No physical mounting was necessary to secure the daughter card in the enclosure because it fit snugly on top of the rubber tubes connected to the cardiograph and pneumograph circuits. Even though the LX4000 DAS units contain only a small amount of electricity, insulation was added in the form of "fishpaper," a common engineering product specially designed for high electrical insulation. The purpose of this was to eliminate any possibility that the daughter card could ever make electrical contact with the main board, enclosure, or the connectors for any of the circuitry. Any contact between the daughter card and the main board, enclosure, or connectors may have resulted in damage to the circuit, but nothing else. Even without the insulation, and even in the most extreme conditions, there has never been any chance that a fault on any LX4000 circuit would present even the slightest danger to a subject or examiner.

The only difference between a unit that was built in 2004 and a unit that was built after 2006 is that the earlier unit used two boards to implement the circuit while later units used a single printed circuit board. The circuit functions the same, measures the same, and is equally safe. The performance and safety of the circuit are dependent upon the engineering design principles used to create it, not on the number of circuit boards used or how the inside of the box looks when someone takes the cover off. Use of a daughter card may represent an issue of aesthetics, but it is not an issue of performance or safety.

Minor changes were made to the design of the LX4000 in 2009, and the new version is referred to internally as the LX4000A. The design changes were made only to facilitate more expedient manufacturing. No changes were made to the performance specifications of the LX4000A.

Additional changes were made to the LX4000 in 2010, and this current version of the LX4000 is referred to internally as the LX4000B. The exterior connectors were modified so that auxiliary channels now include dedicated circuits for seat, hands, and feet activity sensors. At the same time, the LX4000 EDA circuit was changed to the same skin-resistance circuit that was originally designed for the modular LX5000. This change was largely made to simplify part purchasing and product manufacturing. The LX4000B EDA skin-resistance circuit uses a constant current of 6.7 μA and has a range of 10 kΩ to 2 MΩ.

In addition to hardware changes in the EDA circuitry, firmware changes were also made to the LX4000. At the time, firmware changes for LX4000 units required reprogramming of the microprocessor on the main board, and therefore the units needed to be returned to Lafayette Instrument for factory servicing. Firmware changes allowed the processor to handle the increased range of the hardware and provided version identification to the software. The firmware version can be read from the LXSoftware data acquisition screen. There is no signal processing in the firmware, and firmware changes do not affect the EDA waveform.

The LX5000 was introduced in 2008 as a modular system in which sensor modules could be attached directly to the

subject or mounted to a central docking station. The modular design was a response to customer interest in the potential for wireless connection between the DAS and the examinee. Customer interest shifted away from wireless solutions, but interest in the LX5000 itself continued. The LX5000 circuits were therefore re-engineered into a single DAS unit. No changes were made to most of the circuitry, though the EDA circuit was upgraded to have the ability to record either skin-conductance or skin-resistance, with a software option for the user to select the desired EDA mode. The LX5000 skin-conductance/skin-resistance circuit was designed and verified to provide linear response in both skin-resistance and skin-conductance modes. The LX5000 skin-resistance circuit uses a constant current of 4 μA and provides a range of 10 kΩ to 2.5 MΩ. The LX5000 skin-conductance circuit uses a constant voltage circuit that is automatically ranged for each subject at the onset of recording, and will employ a maximum current of 10 μA. The circuit is capable of providing a linear response to changes in conductance while recording data from 5 kΩ to 4 MΩ.

LX4000 AND LX5000 SAFETY

Addressing the safety of the LX4000 and LX5000 requires some understanding of the nature of electrical safety tests. Electrical safety is typically concerned with "line voltage", or the electricity that comes out of a wall outlet. Devices that plug into a wall outlet need to follow specific design criteria to make sure that they are safe, and rightfully so, by preventing the possibility that a person can come into contact with a dangerous voltage level. One international standard for medical equipment, IEC 60601-1, which is the most stringent safety standard, does not consider any voltage under 60 volts (DC) to be a danger. According to this and other standards, if the voltage is less than 60 volts, then engineers are not required to take any special precautions to keep someone from touching it. Although polygraph recording instruments are not actual medical devices, the LX4000 and LX5000 are well within this voltage specification because they are powered by only 5 volts from the USB connector. The LX4000 and LX5000 are thus intrinsically safe to the point where either device could actually be used safely even without an enclosure (although we don't recommend it due to the risk of damage to internal components).

Because the computer that runs the polygraph system is typically plugged into a wall outlet or line voltage, it is necessary to ensure that any electricity that an examinee or examiner could come into contact with does not have any direct path to ground. This safety barrier is accomplished by electrically isolating the EDA electrodes. The EDA is the only sensor that makes electrical contact with the subject. This means that if a subject is wearing the electrodes and happens to touch a high voltage source, there would be no path to ground through the subject and the subject would be safe from potential harm. Isolation is provided in the design of the circuit and is present regardless of whether the circuit resides on one circuit board or two. Again, safety depends on the engineering principles used to design the circuit, not on aesthetics.

LX4000 AND LX5000 STABILITY

Communication from customers indicated some areas for improvement in the LX4000, and changes have been made in response to that feedback. One reported issue was the potential for the DAS unit to become "disconnected" from the computer, resulting in a stoppage of data acquisition. The disconnection was semantic only, as no physical disconnection was reported between the Universal Serial Bus (USB) cable and the computer. Investigation of this condition revealed two causes; one was that the software was initially designed to timeout after approximately 9 hours. This timeout was based on an assumption that the DAS unit and software would not be left in continuous day

and night operation. Users who left a computer and DAS unit running overnight may have found a need to restart the software to resume data acquisition. Software changes have subsequently removed the timeout value, and the device can be left in continuous operation if desired.

Static discharge was also found to sometimes affect the LX4000 connection. Measures taken to minimize this included changing the fabricated metallic device enclosure to an anti-static plastic enclosure. (LX4000 units with metallic enclosures have been and can still be returned to Lafayette Instrument for factory servicing.) Separately, a vulnerability to static discharge was identified with regard to an electronic component within the initial LX4000 design. That component was a serial to USB converter used to connect the DAS to the computer's USB port. The component was subsequently replaced with an electrical component that has been verified as substantially more robust against electrostatic discharge. Additionally, the development of a more effective and more durable activity sensor, using pneumatic sensor technology, allowed the elimination of piezoelectric activity sensors that may have increased the sensitivity of the LX4000 to static discharge in some environments. Finally, both the LX4000B and LX5000 units have passed extensive testing for robustness even when subjected to repeated electrostatic discharge of both the device and the EDA sensor. The result of these changes means that both the LX4000B and LX5000 devices are highly robust against unintentional disconnection of USB data acquisition.

EDA SIGNAL PROCESSING

Manual (i.e. Raw) EDA data for LX4000 and LX5000 devices is sent to the computer via USB after conversion of the electrical signal to digitized values using 24 bit analog-to-digital technology. The firmware does no signal processing. Manual EDA data is provided to the examiner with only the minimum degree of processing necessary to plot the EDA data onto a computer screen or printer. Resistance plots for both the LX4000 and LX5000 have been thoroughly bench tested and verified as linear using standardized engineering resistor boxes.

An Automatic (i.e. self-centering) EDA mode was provided through the LXSoftware software with the introduction of the LX4000. The original Auto EDA filter (now referred to as the Legacy Auto EDA) was not designed around any specified corner frequencies, and was instead designed to return the Legacy Auto EDA trace to the baseline within a specified period of time. Because the LXSoftware was initially designed to replicate the functionality of earlier analog polygraph instruments, the examiner could select either Manual EDA or Legacy Auto EDA modes at the time of data acquisition. Customers later indicated a desire for the ability to change EDA modes after data acquisition, and this capability was added to the LXSoftware. It had long been known that some potential may have existed for numerically scored EDA measurements to differ between the EDA modes under some circumstances, and this new ability to change modes after data acquisition made it possible to study the circumstances under which this might occur. A recent analysis of the Legacy Auto EDA signal processing model shows that the filter functions as a smoothing filter using a first-in-first-out data buffer of 0.5 seconds, followed by a first order high-pass filter with a corner frequency of 0.04 Hz.

In response to concerns about the potential for scoring differences to occur under some circumstances, the Legacy Auto EDA mode was removed from the LXSoftware version 9.9.7 during 2007, and a Detrended EDA mode was implemented instead. The Detrended EDA filter (now referred to as the Legacy Detrended EDA) was designed to reduce the potential for differences in numerical scores when comparing data using the different EDA modes. The

Legacy Detrended EDA was a mathematical solution designed to maintain the EDA data on a stable baseline by monitoring the short term and long term trend activity and adding the conjugate of the waveform slope to the raw data. Customer feedback indicated a desire for a managed EDA mode with perfect or near perfect correspondence between scored sympathetic reaction segments when comparing data in different EDA modes. In response, the Legacy Detrended EDA was replaced with the present Detrended EDA in 2010. The present Detrended EDA filter functions by displaying all upward (sympathetic) EDA data to be plotted and viewed without any filtering or processing, and by removing downward (non-diagnostic) activity after the EDA data have returned to the baseline. The result is a stable and managed Detrended EDA waveform for which sympathetic reaction segments will produce perfect or near perfect correspondence with the reactions observed using the Manual EDA mode. One limitation of the Detrended EDA mode is that some non-diagnostic tonic activity is not made visible to the examiner.

Customer requests for a traditional Auto EDA mode, resulted in the development of a new (current) Auto EDA mode that was added to the system during 2010 beginning with LXSoftware version 11.0. The Auto EDA mode was designed to provide a smooth and stable EDA waveform for which both tonic and phasic changes are easily visualized. The Auto EDA functions through a series of smoothing, low-pass and high-pass filters. The smoothing stage of this filter is an exponentially weighted moving average buffer of 0.33 seconds. Data is passed to a first-order low-pass filter with a corner frequency of 0.5 Hz, and then to a first-order high-pass filter with a corner frequency of 0.5 Hz. The result is an EDA waveform that is stable, conforms to the baseline and provides both tonic and phasic EDA data that is easy to interpret under a wide range of conditions and with a wide range of physiological response profiles.

To further reduce the potential occurrence of numerical score differences between the Auto EDA and Manual EDA modes, Lafayette engineers and researchers have continued to develop improvements in the Auto EDA, including the optimization of Auto EDA corner frequencies through statistical analysis of the EDA data and Fourier analysis of EDA frequency spectra. The design specification of the new Auto EDA includes a smoothing stage using an un-weighted moving average buffer of 0.5 seconds, followed by a first order low-pass filter at 0.5 Hz that removes non-diagnostic high frequency noise, and terminates with a high-pass filter of .01 Hz that better preserves EDA energy in the spectrum of interest to the polygraph examiner (.01 Hz to 0.5 Hz) while returning the data to a stable baseline. The new Auto EDA data will provide a stable baseline, while also displaying more tonic activity than the Detrended EDA mode and more complex activity than the current Auto EDA. In a practical sense this means that the Auto EDA will correspond more closely to the waveforms of the Manual EDA while remaining highly usable with a wider range of persons, and while further reducing the potential for scoring differences to the minimum level possible.

The potential to observe differences in numerical scores under certain circumstances, when using different EDA signal processing solutions, has been discussed for decades within the polygraph profession. Those circumstances are now known to be related primarily to complex reaction segments, which have themselves been reported in the scientific literature as unreliably correlated with differential responding to test stimuli during comparison question testing. The potential for scoring differences is unrelated to the LX4000 or LX5000 circuitry, and is not limited to the Lafayette polygraph instrument; instead this potential should be assumed to apply to all instruments that provide both manual and automatic/filtered EDA solutions. The ability to observe this phenomena was not available using earlier versions of computerized data acquisition systems because they were designed to mimic the functionality of analog instrumentation and so did not permit the comparison of EDA signal processing solutions. Awareness of this potential has increased in recent years as a result of design innovations at Lafayette Instrument, making it possible

to study this known phenomenon. This also led to the design and development of the Detrended EDA mode, which offers field examiners a managed EDA solution for which the numerical scores will correlate perfectly with those obtained using the Manual EDA mode. Although scoring differences between Manual EDA and Auto EDA modes are considered to occur only on rare occasions, Lafayette researchers are presently quantifying the rate of occurrence, and developing improvements to further reduce the occurrence to zero or near zero levels. The research will be published once completed.

CONCLUSION

Lafayette Instrument Company endeavors to provide the highest quality instrumentation and data acquisition systems to professional in the polygraph profession and life sciences, including field practitioners in government, law-enforcement and private agencies, and researchers in academic, government and proprietary or industrial settings, as we have for over 50 years.

Lafayette Instrument Company will continue to lead, innovate, and provide robust solutions based on the latest engineering and safety standards. Lafayette Instrument Company is committed to the development of these products and technologies, and will continue to subject new technologies to thorough safety and usability testing in addition to scientific review. Lafayette Instrument Company desires to continue to meet the requirements of the polygraph profession by providing superior support and the best instrumentation available.

Questions and feedback are always welcome, and we will continue to provide detailed information where needed in response to questions, criticisms, or academic and scientific inquiry.

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Changing the EDA circuit involved adding new electronic components, resulting in an auxiliary circuit board that was installed as a daughter card inside the LX4000 DAS enclosure. The new circuit was provided to existing customers upon request. To install the new circuit, the DAS unit had to be returned for factory servicing. The EDA daughter card was also added to some DAS devices during new production. Use of the daughter card installation allowed Lafayette to quickly meet demands for new production and servicing of existing units. The latest date of production for devices with the EDA daughter card was 2006. LX4000 DAS units sold after 2006 had the new EDA circuit included on the main board.

No physical mounting was necessary to secure the daughter card in the enclosure because it fit snugly on top of the rubber tubes connected to the cardiograph and pneumograph circuits. Even though the LX4000 DAS units contain only a small amount of electricity, insulation was added in the form of "fishpaper," a common engineering product specially designed for high electrical insulation. The purpose of this was to eliminate any possibility that the daughter card could ever make electrical contact with the main board, enclosure, or the connectors for any of the circuitry. Any contact between the daughter card and the main board, enclosure, or connectors may have resulted in damage to the circuit, but nothing else. Even without the insulation, and even in the most extreme conditions, there has never been any chance that a fault on any LX4000 circuit would present even the slightest danger to a subject or examiner.

The only difference between a unit that was built in 2004 and a unit that was built after 2006 is that the earlier unit used two boards to implement the circuit while later units used a single printed circuit board. The circuit functions the same, measures the same, and is equally safe. The performance and safety of the circuit are dependent upon the engineering design principles used to create it, not on the number of circuit boards used or how the inside of the box looks when someone takes the cover off. Use of a daughter card may represent an issue of aesthetics, but it is not an issue of performance or safety.

Minor changes were made to the design of the LX4000 in 2009, and the new version is referred to internally as the LX4000A. The design changes were made only to facilitate more expedient manufacturing. No changes were made to the performance specifications of the LX4000A.

Additional changes were made to the LX4000 in 2010, and this current version of the LX4000 is referred to internally as the LX4000B. The exterior connectors were modified so that auxiliary channels now include dedicated circuits for seat, hands, and feet activity sensors. At the same time, the LX4000 EDA circuit was changed to the same skin-resistance circuit that was originally designed for the modular LX5000. This change was largely made to simplify part purchasing and product manufacturing. The LX4000B EDA skin-resistance circuit uses a constant current of 6.7 μA and has a range of 10 kΩ to 2 MΩ.

In addition to hardware changes in the EDA circuitry, firmware changes were also made to the LX4000. At the time, firmware changes for LX4000 units required reprogramming of the microprocessor on the main board, and therefore the units needed to be returned to Lafayette Instrument for factory servicing. Firmware changes allowed the processor to handle the increased range of the hardware and provided version identification to the software. The firmware version can be read from the LXSoftware data acquisition screen. There is no signal processing in the firmware, and firmware changes do not affect the EDA waveform.

The LX5000 was introduced in 2008 as a modular system in which sensor modules could be attached directly to the subject or mounted to a central docking station. The modular design was a response to customer interest in the potential for wireless connection between the DAS and the examinee. Customer interest shifted away from wireless solutions, but interest in the LX5000 itself continued. The LX5000 circuits were therefore re-engineered into a single DAS unit. No changes were made to most of the circuitry, though the EDA circuit was upgraded to have the ability to record either skin-conductance or skin-resistance, with a software option for the user to select the desired EDA mode. The LX5000 skin-conductance/skin-resistance circuit was designed and verified to provide linear response in both skin-resistance and skin-conductance modes. The LX5000 skin-resistance circuit uses a constant current of 4 μA and provides a range of 10 kΩ to 2.5 MΩ. The LX5000 skin-conductance circuit uses a constant voltage circuit that is automatically ranged for each subject at the onset of recording, and will employ a maximum current of 10 μA. The circuit is capable of providing a linear response to changes in conductance while recording data from 5 kΩ to 4 MΩ.

LX4000 and LX5000 Safety

Addressing the safety of the LX4000 and LX5000 requires some understanding of the nature of electrical safety tests. Electrical safety is typically concerned with "line voltage", or the electricity that comes out of a wall outlet. Devices that plug into a wall outlet need to follow specific design criteria to make sure that they are safe, and rightfully so, by preventing the possibility that a person can come into contact with a dangerous voltage level. One international standard for medical equipment, IEC 60601-1, which is the most stringent safety standard, does not consider any voltage under 60 volts (DC) to be a danger. According to this and other standards, if the voltage is less than 60 volts, then engineers are not required to take any special precautions to keep someone from touching it. Although polygraph recording instruments are not actual medical devices, the LX4000 and LX5000 are well within this voltage specification because they are powered by only 5 volts from the USB connector. The LX4000 and LX5000 are thus intrinsically safe to the point where either device could actually be used safely even without an enclosure (although we don't recommend it due to the risk of damage to internal components).

Because the computer that runs the polygraph system is typically plugged into a wall outlet or line voltage, it is necessary to ensure that any electricity that an examinee or examiner could come into contact with does not have any direct path to ground. This safety barrier is accomplished by electrically isolating the EDA electrodes. The EDA is the only sensor that makes electrical contact with the subject. This means that if a subject is wearing the electrodes and happens to touch a high voltage source, there would be no path to ground through the subject and the subject would be safe from potential harm. Isolation is provided in the design of the circuit and is present regardless of whether the circuit resides on one circuit board or two. Again, safety depends on the engineering principles used to design the circuit, not on aesthetics.

LX4000 and LX5000 Stability

Communication from customers indicated some areas for improvement in the LX4000, and changes have been made in response to that feedback. One reported issue was the potential for the DAS unit to become "disconnected" from the computer, resulting in a stoppage of data acquisition. The disconnection was semantic only, as no physical disconnection was reported between the Universal Serial Bus (USB) cable and the computer. Investigation of this condition revealed two causes; one was that the software was initially designed to timeout after approximately 9 hours. This timeout was based on an assumption that the DAS unit and software would not be left in continuous day and night operation. Users who left a computer and DAS unit running overnight may have found a need to restart the software to resume data acquisition. Software changes have subsequently removed the timeout value, and the device can be left in continuous operation if desired.

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sensor, using pneumatic sensor technology, allowed the elimination of piezoelectric activity sensors that may have increased the sensitivity of the LX4000 to static discharge in some environments. Finally, both the LX4000B and LX5000 units have passed extensive testing for robustness even when subjected to repeated electrostatic discharge of both the device and the EDA sensor. The result of these changes means that both the LX4000B and LX5000 devices are highly robust against unintentional disconnection of USB data acquisition.

EDA Signal Processing

Manual (i.e. Raw) EDA data for LX4000 and LX5000 devices is sent to the computer via USB after conversion of the electrical signal to digitized values using 24 bit analog-to-digital technology. The firmware does no signal processing. Manual EDA data is provided to the examiner with only the minimum degree of processing necessary to plot the EDA data onto a computer screen or printer. Resistance plots for both the LX4000 and LX5000 have been thoroughly bench tested and verified as linear using standardized engineering resistor boxes.

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In response to concerns about the potential for scoring differences to occur under some circumstances, the Legacy Auto EDA mode was removed from the LXSoftware version 9.9.7 during 2007, and a Detrended EDA mode was implemented instead. The Detrended EDA filter (now referred to as the Legacy Detrended EDA) was designed to reduce the potential for differences in numerical scores when comparing data using the different EDA modes. The Legacy Detrended EDA was a mathematical solution designed to maintain the EDA data on a stable baseline by monitoring the short term and long term trend activity and adding the conjugate of the waveform slope to the raw data.
Customer feedback indicated a desire for a managed EDA mode with perfect or near perfect correspondence between scored sympathetic reaction segments when comparing data in different EDA modes. In response, the Legacy Detrended EDA was replaced with the present Detrended EDA in 2010. The present Detrended EDA filter functions by displaying all upward (sympathetic) EDA data to be plotted and viewed without any filtering or processing, and by removing downward (non-diagnostic) activity after the EDA data have returned to the baseline. The result is a stable and managed Detrended EDA waveform for which sympathetic reaction segments will produce perfect or near perfect correspondence with the reactions observed using the Manual EDA mode. One limitation of the Detrended EDA mode is that some non-diagnostic tonic activity is not made visible to the examiner.

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Conclusion

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Lafayette Instrument Company will continue to lead, innovate, and provide robust solutions based on the latest engineering and safety standards. Lafayette Instrument Company is committed to the development of these products and technologies, and will continue to subject new technologies to thorough safety and usability testing in addition to scientific review. Lafayette Instrument Company desires to continue to meet the requirements of the polygraph profession by providing superior support and the best instrumentation available.

Questions and feedback are always welcome, and we will continue to provide detailed information where needed in response to questions, criticisms, or academic and scientific inquiry.

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